

P
mix

NASA TECHNICAL NOTE



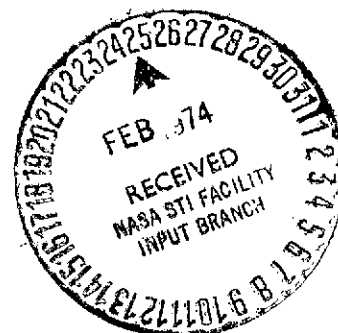
NASA TN D-7555

NASA TN D-7555

(NASA-TN-D-7555) EFFECTS OF PRESSURE,
OXYGEN CONCENTRATION, AND FORCED
CONVECTION ON FLAME SPREAD RATE OF
PLEXIGLAS, NYLON AND TEFLON (NASA)
HC \$3.00

N74-16621

28 p
CSCL 21B H1/33 29218
Unclas



**EFFECTS OF PRESSURE,
OXYGEN CONCENTRATION, AND FORCED
CONVECTION ON FLAME SPREAD RATE
OF PLEXIGLAS, NYLON, AND TEFLON**

*by Julius J. Notardonato, Leo A. Burkhardt,
and Thomas H. Cochran*

*Lewis Research Center
Cleveland, Ohio 44135*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1974

1. Report No. NASA TN D-7555		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle EFFECTS OF PRESSURE, OXYGEN CONCENTRATION, AND FORCED CONVECTION ON FLAME SPREAD RATE OF PLEXIGLAS, NYLON, AND TEFLON				5. Report Date February 1974	
				6. Performing Organization Code	
7. Author(s) Julius J. Notardonato, Leo A. Burkhardt, and Thomas H. Cochran				8. Performing Organization Report No. E-7611	
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135				10. Work Unit No. 502-28	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				13. Type of Report and Period Covered Technical Note	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract Experiments were conducted in which the burning of cylindrical materials in a flowing oxidant stream was studied. Plexiglas, nylon, and Teflon fuel specimens were oriented such that the flames spread along the surface in a direction opposed to the flowing gas. Correlations of flame spread rate were obtained that were power law relations in terms of pressure, oxygen concentration, and gas velocity.					
17. Key Words (Suggested by Author(s)) Polymeric Combustion Flame spread rate Oxygen safety				18. Distribution Statement Unclassified - unlimited Cat. 33	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 26 28	
				22. Price* \$3.00	

* For sale by the National Technical Information Service, Springfield, Virginia 22151

EFFECTS OF PRESSURE, OXYGEN CONCENTRATION, AND FORCED CONVECTION ON FLAME SPREAD RATE OF PLEXIGLAS, NYLON, AND TEFLON

by Julius J. Notardonato, Leo A. Burkhardt, and Thomas H. Cochran

Lewis Research Center

SUMMARY

Experiments were conducted in which the burning of cylindrical materials in a flowing oxidant stream was studied. Plexiglas, nylon, and Teflon fuel specimens were oriented such that the flames spread along the surface in a direction opposed to the flowing gas. Results of the effects of pressure, oxygen concentration, and gas velocity on flame spread rate substantiated and extended the work in the literature. Three regions were defined for the behavior of the flame spread rate as a function of gas velocity. Sufficient information was obtained in two of the regions to provide data correlations which were power law relations in terms of pressure, oxygen concentration, and gas velocity.

INTRODUCTION

The burning characteristics of solid materials have been the subject of numerous studies in the recent past (refs. 1 to 3). This interest is the result of expanded emphasis on industrial, as well as domestic, safety practices. A particular kind of burning which is receiving considerable attention is combustion in an oxygen-rich environment. Accidents, some with loss of life, that have occurred in hospitals (ref. 4), in research establishments (ref. 5), and in the space program (ref. 6) underline the necessity of this research.

The vast majority of the work that has been done in this field has been concerned with burning in initially quiescent environments. However, many applications involve flowing oxygen systems. A recent thesis by Lastrina (ref. 7) investigated the effects of forced convection motion opposed to the flame spread on flat polymeric fuels. In these experiments the gas velocity ranged from approximately 18 to 1200 centimeters per second while the oxygen mole fraction was varied from 0.4 to 1. The diluents used were argon, helium, and nitrogen. The results indicated that the flame spread rate increased

with increasing gas velocity until a critical value was reached. Further increases in gas velocity resulted in a decrease in the flame spread rate. The data were correlated using a power law relation which raised the gas velocity to the one-third power and the oxygen mole fraction to a power which was dependent on material.

The work reported herein extends the work of Lastrina to a different geometry (i.e., cylindrical) and higher pressures. Plexiglas (methyl methacrylate), nylon (Zytel 101), and Teflon (TFE) specimens were burned at various pressures, to approximately 75 atmospheres, in environments ranging from pure oxygen to 20 percent oxygen - 80 percent nitrogen. The average gas velocity was varied up to about 900 centimeters per second. High-speed 16-millimeter motion pictures were taken to measure the rate of flame spread as well as to study the flame geometry.

SYMBOLS

a	power to which oxygen mole fraction is raised in power law correlation
b	power to which pressure is raised in power law correlation
K_1	constant in region I correlation
K_2	constant in region II correlation
P	pressure
v_f	average flame spread rate
v_g	average gas velocity
Y_{ox}	oxygen mole fraction

APPARATUS AND PROCEDURE

Apparatus

The test system consisted of a chamber, a nitrogen-oxygen supply system, and a gas exhaust system. The test chamber, figure 1(a), was a 10.16-centimeter-internal-diameter steel pipe which was mounted vertically. Two 13.97-centimeter by 2.54-centimeter view ports were spaced 180° apart. The test specimens (0.64-cm-diam, 11.43-cm-long rods) were mounted along the centerline of the test chamber and ignited at the top with a nichrome wire. A mixture of oxygen and nitrogen gases entered at the bottom of the test chamber and flowed by the specimen. The gas mixture of combustion

products, oxygen, and nitrogen was exhausted from the top of the chamber. A schematic of the oxygen and nitrogen supply systems and the exhaust system is shown in figure 1(b).

The mass flow rates of oxygen and nitrogen were measured with calibrated orifices. A photographic record of the burning specimen was made using 16-millimeter color motion-picture film at a framing rate of 64 frames per second. The chamber pressure, the orifice upstream gas pressures and temperatures, and the pressure drop across the orifices were recorded by an oscillograph.

Test Procedure

The test samples were washed with soap and rinsed several times in warm water. Then, being careful to touch the specimens only at the tip where the igniter was to be installed, we mounted the specimens and installed the igniter.

After the specimen assembly was installed in the test chamber, the exhaust vent was opened fully and the oxygen and nitrogen mass flow rates were set. After the desired flow rates were obtained, the exhaust valve was set to control chamber pressure. The oscillograph and motion-picture camera were started and the specimen ignited. After the flame spread to the bottom of the specimen, an abort system was activated. This system fully opened the exhaust valve, shut off the oxygen, and allowed the specimen to be quenched by the nitrogen flow. If the test was being run in pure oxygen, the abort system would automatically open the nitrogen valve to a preset value.

Specific tests were performed to compare the mass consumption rate of nylon with that of Teflon. These specimens were prepared as previously described with the exception that the ignition wire was wrapped spirally, in three loops, around their length. Thus, the entire surface was ignited almost instantaneously. After a preset time, the flame was quenched with nitrogen.

Data Analysis

The flame spread rate was measured by counting the number of motion-picture frames that were used while the specimens burned over a 5.08-centimeter section. The motion pictures were also used to study flame characteristics of the burning specimens. To avoid any ignition effects, the starting point for measuring the flame spread rate was chosen to be approximately 5.08 centimeters from the top of the specimen.

For the nylon and Teflon mass consumption rate tests, the mass consumption rate was determined from the weights of the specimens before and after testing and from the burning times.

Gas flow velocity past the specimen was calculated from the one-dimensional continuity equation.

RESULTS AND DISCUSSION

Experimental Data

The tests were conducted in such a manner that the effects of each of the independent variables (pressure, oxygen concentration, and gas velocity) on flame spread rate were systematically studied. Accordingly, the presentation of the data corresponds to the sequence in which the experiments were conducted.

Effects of pressure. - The effects of pressure on flame spread rate were studied for each of the materials at a gas velocity of approximately 16 centimeters per second in a pure oxygen environment. The pressure was varied from about 1 to 75 atmospheres. Typical examples of the materials burning at low gas velocities are shown in figure 2. The flame spread rates are cataloged in table I and presented graphically in figure 3.

Shown in figure 3 for each material is a solid curve representing the pressure dependence reported by Magee and McAlevy (ref. 8). Their work was conducted with flat specimens in initially quiescent environments at pressures to 28 atmospheres. It is evident from the figure that there is good agreement between the experimental data of this study and reference 8 even though the material geometries were significantly different, forced convection was present, and higher pressures were used in this study. To further check this agreement, least-squares curves were determined for each material. The results showed flame spread rate to be proportional to pressure to the 0.71 power for Plexiglas, to the 0.67 power for nylon, and to the 1.2 power for Teflon. The difference between these exponents and those of reference 8 is probably caused by data scatter.

A comment regarding the scatter in the data as shown in figure 3 is warranted. The data are rather severely scattered about the curves for both nylon and Teflon. For instance, at 35 atmospheres the identical test condition resulted in an almost 2-to-1 variation in flame spread rate. A possible cause for this behavior is that the free convective velocities, which would have a tendency to be nonsteady as indicated by the observed pulsating of the flames, could have been of the same order of magnitude as the forced convection velocities for these tests.

Examination of the motion pictures revealed an effect of pressure on the flame geometry. Figure 4 shows nylon burning at three pressure levels: 1, 20, and 62 atmospheres. With increasing pressure, the flame became brighter and more compact. Apparently, the greater density of oxygen molecules as the pressure increased caused oxygen to diffuse into the pyrolysis gas quicker, thus moving the combustion zone closer to the specimen.

Effects of oxygen concentration. - The effects of oxygen concentration on flame spread rate were studied in an environment in which the gas velocity was approximately 15 centimeters per second and the pressure was about 7 atmospheres. The results are presented in table II and shown in figure 5.

The general trend of all the data was that a decrease in oxygen concentration resulted in a decrease in flame spread rate. For the Plexiglas data, the solid line in figure 5 represents a variation of flame spread rate with oxygen mole fraction to the 1.94 power. This is the dependence reported in reference 7 for flame spreading on flat methacrylate specimens in forced convective oxygen-nitrogen systems. Again, there appears to be good agreement between the present data and those in the literature.

There is nothing available that can be directly compared to the nylon and Teflon data. Therefore, least-squares curves were fit to these results, and they are indicated by the dashed lines. The nylon data varied with the oxygen mole fraction to the 1.5 power, while the limited Teflon data indicated a dependence on oxygen mole fraction to the 5.7 power.

Figure 6 shows how the flame intensity varied with oxygen concentration for nylon. The effect is similar to that shown in figure 4 for increasing pressure in pure oxygen systems. That is, the flame becomes brighter and more compact with increasing oxygen concentration at a given pressure.

Effects of gas velocity. - The tests performed to investigate the effects of gas velocity on flame spread rate were conducted in a pure oxygen environment. For Plexiglas and nylon, data were obtained over a range of gas velocities at four different pressure levels: approximately 7, 20, 35, and 68 atmospheres. The Teflon tests were conducted at about 20, 35, and 68 atmospheres. The data are presented in table III and figure 7.

It is apparent from figure 7 that, for Plexiglas and nylon at a given pressure level, the flame spread rate increased with increasing gas velocity until a critical value was reached. The solid lines represent a variation of flame spread rate with gas velocity to the one-third power. This dependence, which was reported previously by Lastrina in reference 7, is representative of the trends in the data as evidenced by the scatter of the points about the appropriate curves. Lastrina also reported the existence of the critical point beyond which increases in gas velocity result in a decrease in flame spread rate.

The dashed lines in the figure have been faired through the data to indicate trends. Beyond the critical point, the flame spread rate at first seemed to decrease relatively slowly with increasing gas velocity. In the case of Plexiglas at low pressure, further increases in gas velocity resulted in a rapid decrease in flame spread rate, and extinguishment was imminent. However, for nylon, only the 7-atmosphere tests behaved in this manner. The higher pressure tests show the flame spread rate going through another inflection point, beyond which a relatively rapid increase in flame spread rate with increasing gas velocity is apparent. To facilitate further discussion and treatment of the data,

figure 7 is divided into three regions which reflect the response of flame spread rate to gas velocity as just discussed.

Considering now the Teflon data (fig. 7(c)), it can be seen that only regions II and III were evident. The broken lines represent a change in flame spread rate with gas velocity to the minus one-half power as determined by least-squares methods. Again, the dashed curves indicate trends in the data.

The motion-picture films indicate that in both regions I and II the flame boundary moved closer to the specimen with increasing gas velocity, as shown in figure 8. This same trend was noticed with increasing pressure and oxygen concentration, as shown in figures 4 and 6, respectively. Another effect evident in the motion pictures was the amount of char left on the specimens. As shown in figure 9, the amount of char remaining on the nylon decreases with increasing gas velocity. This effect was also observed in the Plexiglas tests.

Mass consumption rates. - The effect of pressure on the mass consumption rates of nylon and Teflon was investigated by burning identical specimens. The results are presented in table IV. As shown in figure 10, Teflon is consumed at a faster rate than nylon at a given pressure. This was particularly true under conditions that enhanced burning, such as higher pressures. The fact that Teflon is almost twice as dense as nylon contributes to this difference.

Correlations

Region I. - A power law relation of the form

$$v_f \propto K_1 Y_{ox}^a P_g^b v_g^{1/3} \quad (1)$$

is suggested in reference 8 as a correlation for flame spread rate. The results that have been presented so far have shown that the dependence of flame spread rate on oxidant concentration and pressure at a particular low forced convection velocity, as well as its dependence on gas velocity at different set pressures, agrees with the work of other investigators. However, it remained to test generally the correlation proposed by equation (1). The results of this analysis are shown in figure 11, where all the data for Plexiglas and nylon in region I from tables I to III have been plotted. The solid curves are lines with a slope of 1 that have been faired through the data. It is apparent that there are quantitative data that validate the proposed correlation over two orders of magnitude. The proportionality constants K_1 are 0.27 for Plexiglas and 0.14 for nylon.

Region II. - In keeping with the power law relation, a sequel correlation to that of region I is proposed for region II in the form

$$v_f \propto K_2 Y_{ox}^a P_v^b v_g^{-1/2} \quad (2)$$

The region II data from tables I to III for Plexiglas, nylon, and Teflon are plotted in figure 12. Again, the lines have a slope of 1 and have been faired through the data points. The agreement shown in the figure would seem to provide at least qualitative substantiation of the correlation. The proportionality constants K_2 are 15 for Plexiglas, 6.6 for nylon, and 0.021 for Teflon.

Discussion

The region I data for the effects of pressure, oxygen concentration, and gas velocity on flame spread rate indicate that increases in these parameters result in a greater flame spread rate. In addition, the motion-picture films show that the flames appeared to move closer to the fuel and become more intense as these parameters became larger. It would seem that the increased availability of oxygen due to higher gas density, greater concentration, and/or increased convection accounts for this result. The fact that the char on the specimens decreased with greater velocity also indicates the existence of a more efficient combustion process under these conditions.

In region II, although the flame boundary continued to move closer to the fuel, the flame spread rate decreased with increasing gas velocity. A potential explanation for this behavior is that the convection effects became great enough to start to detract from the combustion process by removal of energy and reactants from the leading edge of the flame.

The experimental results indicate that the dependence of flame spread rate on pressure and gas velocity in region III is complex. This, together with the fact that not much data could be obtained there, requires that meaningful conclusions regarding the mechanisms controlling flame spread rate be left for further experimentation. Suffice it to say that the region has been identified.

SUMMARY OF RESULTS

Experiments were conducted in which the burning of cylindrical fuel specimens in a flowing oxidant stream was studied. The materials used were Plexiglas, nylon, and Teflon. Orientation of the fuels was such that the flame spread along the solid surface in

a direction opposed to the flowing gas. Pressure, oxygen concentration, and gas velocity were varied separately so that their effect on flame spread rate could be assessed.

Results concerning the effects of pressure P on flame spread rate v_f indicated agreement with other work in the literature, that is, for Plexiglas, $v_f \sim P^{0.82}$; for nylon, $v_f \sim P^{0.75}$; for Teflon, $v_f \sim P^{1.1}$. Of interest is the fact that the data in the literature are for a totally different fuel geometry (a flat surface) and a quiescent environment. In addition, the results extend the data from the previously reported 28 atmospheres to 75 atmospheres.

Data on the effects of oxygen concentration Y_{ox} on flame spread rate for Plexiglas also agreed with reported results, that is, $v_f \sim Y_{ox}^{1.94}$. Since there were no data available in the literature for nylon and Teflon, least-squares methods were used to show $v_f \sim Y_{ox}^{1.5}$ and $v_f \sim Y_{ox}^{5.7}$ for nylon and Teflon, respectively.

Tests conducted to show the effects of gas velocity v_g identified the existence of three regions defined in terms of the dependence of flame spread rate on the gas velocity. In the first region the data were successfully correlated by a power law relation of the form

$$v_f = K_1 Y_{ox}^a P^b v_g^{1/3}$$

where $K_1 = 0.27$ for Plexiglas and 0.14 for nylon. The exponents a and b were defined for each material as just discussed. The one-third power dependence of the gas velocity and the existence of a critical gas velocity above which further increases in gas velocity resulted in a decrease in flame spread rate reflect other work reported in the literature. In the second region the data were correlated by the equation

$$v_f = K_2 Y_{ox}^a P^b v_g^{-1/2}$$

where $K_2 = 15$ for Plexiglas, 6.6 for nylon, and 0.021 for Teflon. In the third region the flame spread rate was a complex function of pressure and gas velocity. No correlation was obtained for the results in this region.

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, September 24, 1973,

502-28.

REFERENCES

1. Sirignano, W. A.: A Critical Discussion of Theories of Flame Spread Across Solid and Liquid Fuels. Combustion Sci. Tech, vol. 6, nos. 1 and 2, Sept. 1972, pp. 95-105.
2. Kim, J. S.; deRis, J. N.; and Kroesser, F. William: Laminar Free-Convective Burning of Fuel Surfaces. Ser. No. 19720-1, Flammability Materials Research Center, Apr. 1970.
3. Robertson, A. F.; and Rappaport, M. W.: Fire Extinguishment in Oxygen Enriched Atmospheres. NASA CR-121150, 1973.
4. Anon.: Highway Accident Report of Liquified Oxygen Tank-Truck Explosion Followed by Fires in Brooklyn, New York, May 30, 1970. Rep. NTSB-HAR-71-6, National Transportation Safety Board, New York, May 1971.
5. Anon.: Proceedings of Fire Hazards and Extinguishment Conference. Air Force Systems Command, Brooks Air Force Base, Tex., May 1967.
6. Anon.: Manned Space Flight Report and Actions Taken as a Result of the AS-204 Accident. NASA TM X-61455, 1968.
7. Lastrina, Frank A.: Flame Spreading Over Solid Fuel Beds: Solid and Gas Phase Energy Considerations. Ph.D. Thesis., Stevens Institute of Technology, 1970.
8. Magee, R. S.; and McAlevy, R. F., III: The Mechanism of Flame Spread. J. Fire Flammability, Vol. 2, Oct. 1971, pp. 271-297.

TABLE I. - EFFECTS OF PRESSURE ON
FLAME SPREAD RATE

[Oxygen concentration, 1.0 mole fraction.]

Fuel	Test	Gas velocity, cm/sec	Gas pressure, atm	Average flame spread rate, cm/sec
Plexiglas	1	21	1.0	1.32
	2	16	3.3	2.29
	3	16	6.8	3.64
	4	16	6.8	3.78
	5	18	21.8	8.50
	6	16	47.8	17.00
	7	16	75.2	25.20
	8	16	6.8	2.78
Nylon	1	25	1.0	0.50
	2	16	3.6	.96
	3	↓	6.9	1.57
	4		6.9	1.46
	5		6.7	1.39
	6		20.6	2.41
	7	18	20.6	2.83
	8	20	34.3	5.29
	9	16	34.9	3.25
	10	↓	34.6	4.21
	11		35.4	3.04
	12		47.8	9.48
	13		62.4	8.21
	14	↓	75.4	8.51
Teflon	1	17	6.6	0.03
	2	16	20.9	.35
	3	16	34.2	.47
	4	15	35.1	.24
	5	16	34.4	.35
	6	16	47.8	.25
	7	15	61.9	.66
	8	14	75.2	.71

TABLE II. - EFFECTS OF OXYGEN CONCENTRATION ON
FLAME SPREAD RATE

Fuel	Test	Gas velocity, cm/sec	Gas pressure, atm	Oxygen concentration, mole fraction	Average flame spread rate, cm/sec
Plexiglas	9	13	6.8	0.905	2.55
	10	15	7.3	.824	2.54
	11	16	7.1	.738	1.75
	12	13	6.8	.579	1.83
	13	14	6.8	.351	.77
	14	14	6.8	.239	.30
Nylon	15	21	6.6	0.943	1.37
	16	14	7.5	.892	1.07
	17	16	7.5	.808	.93
	18	16	6.6	.717	.70
	19	16	6.6	.600	.66
	20	14	7.2	.552	.67
	21	16	6.6	.324	.24
Teflon	9	13	7.4	0.905	0.01
	10	15	7.1	.824	.01
	11	15	7.4	.695	(a)
	12	15	6.9	.583	(a)
	13	13	6.9	.526	(a)

^aNo flame propagation apparent in these tests.

TABLE III. - EFFECTS OF GAS VELOCITY ON

FLAME SPREAD RATE

[Oxygen concentration, 1.0 mole fraction.]

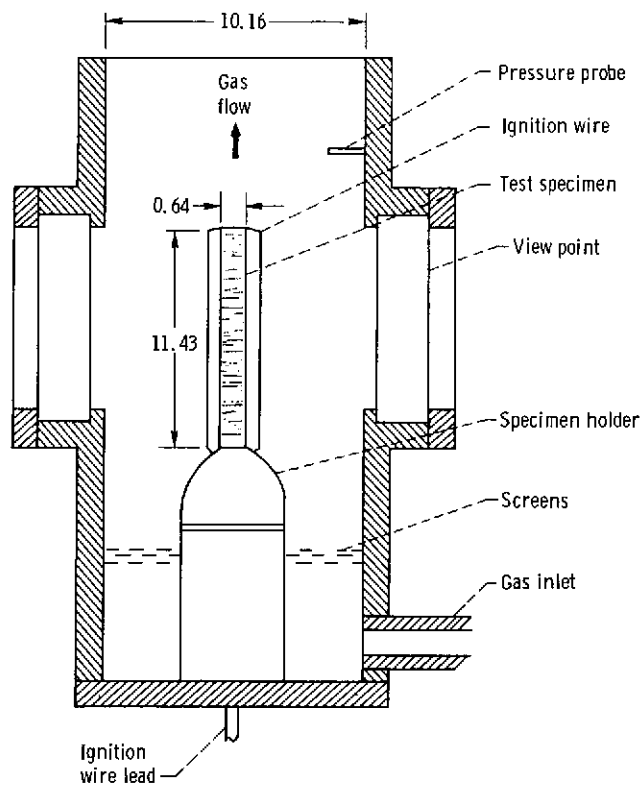
Fuel	Test	Gas velocity, cm/sec	Gas pressure, atm	Average flame spread rate, cm/sec
Plexiglas	15	15	6.8	2.86
	16	33	6.6	4.27
	17	67	6.6	5.60
	18	161	6.6	6.34
	19	305	6.8	4.16
	20	701	7.1	.80
	21	884	7.1	.34
	22	146	6.8	5.90
	23	17	21.1	9.29
	24	23	21.6	8.13
	25	49	19.7	13.54
	26	111	21.4	13.54
	27	167	21.4	14.78
	28	465	19.9	4.64
	29	14	35.1	11.61
	30	28	33.7	16.25
	31	52	34.7	15.48
	32	113	36.0	19.12
	33	176	35.7	18.10
	34	300	34.7	15.48
	35	15	66.9	25.00
	36	28	68.9	29.56
	37	28	68.6	21.67
	38	60	69.9	29.56
	39	130	68.8	46.45
	40	157	68.6	36.12
Nylon	22	36	6.6	2.37
	23	79	6.6	2.43
	24	149	7.2	2.88
	25	305	6.9	1.54
	26	580	6.8	.93
	27	853	6.9	.19
	28	137	6.8	1.39
	29	128	6.9	1.46
	30	18	21.2	4.58
	31	27	21.2	3.92
	32	48	19.7	6.00
	33	116	21.4	5.00
	34	170	21.7	6.50
	35	275	21.9	2.62
	36	464	19.9	9.84
	37	14	34.6	6.25
	38	28	33.7	7.56
	39	52	34.9	5.80
	40	111	36.0	11.61
	41	174	35.7	10.84
Teflon	14	27	21.6	0.13
	15	49	19.7	.09
	16	112	21.4	.08
	17	14	35.6	.23
	18	28	33.7	.17
	19	53	35.2	.17
	20	113	36.0	.16
	21	174	36.3	.36
	22	14	67.3	.63
	23	28	69.4	.44
	24	59	70.1	.24
	25	127	68.4	.50
	26	155	68.6	.37

TABLE IV. - EFFECTS OF PRESSURE

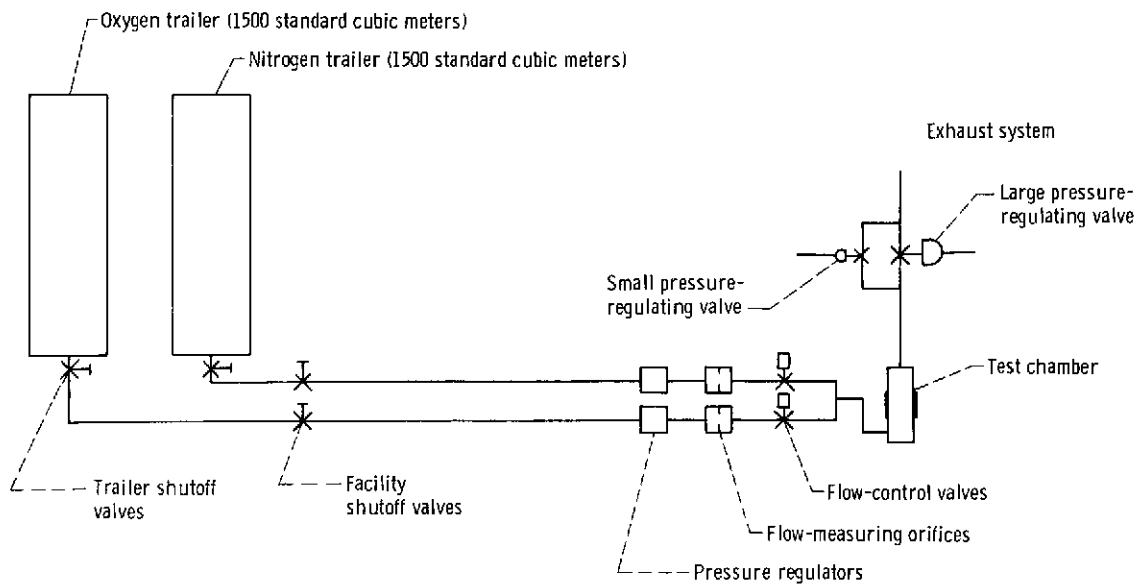
ON MASS CONSUMPTION RATE

[Gas velocity, 16 cm/sec; oxygen concentration, 1.0 mole fraction.]

Fuel	Test	Gas pressure, atm	Mass consumption rate, g/sec
Teflon	1	8.0	0.165
	2	36.5	.265
	3	70	.365
Nylon	1	8.0	0.120
	2	36.5	.125
	3	70	.195



(a) Test chamber.

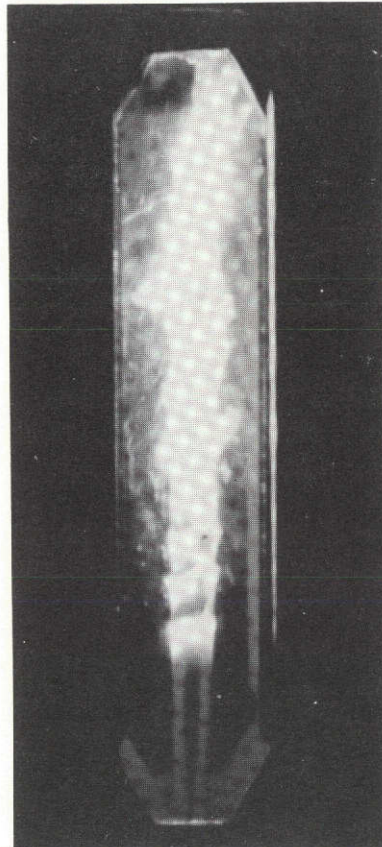


(b) Flow system.

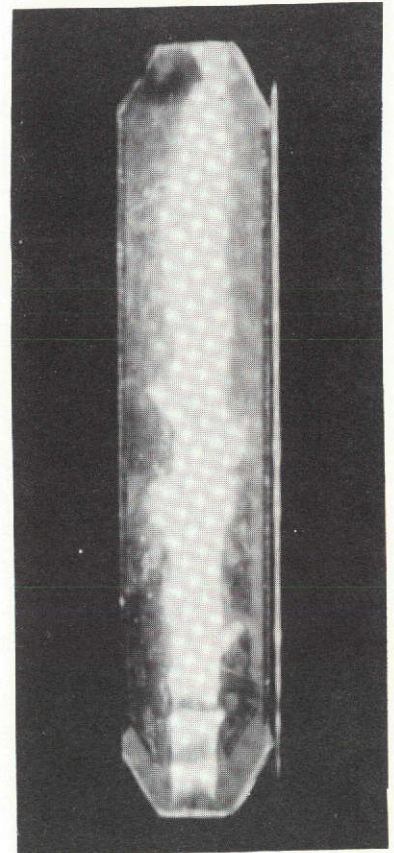
Figure 1. - Schematics of test chamber and flow system. Dimensions are in centimeters.



Time, T_1



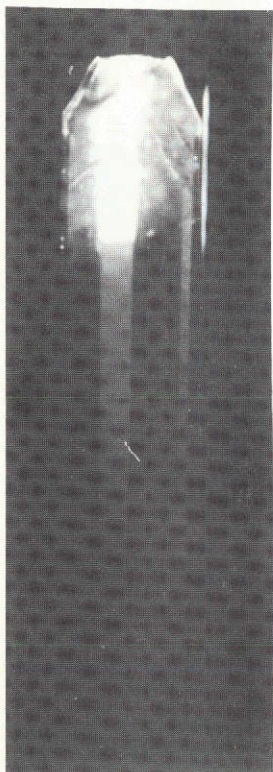
Time, T_2



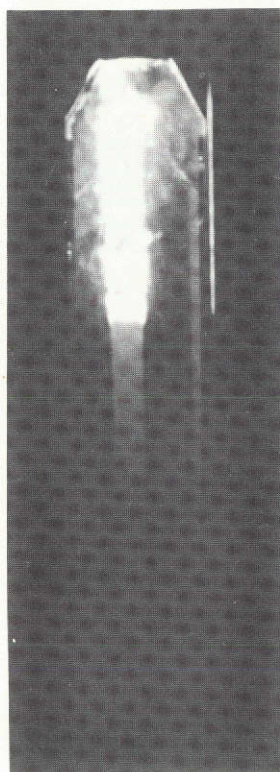
Time, T_3 (where $T_3 > T_2 > T_1$)

(a) Plexiglas; pressure, ~ 47 atmospheres.

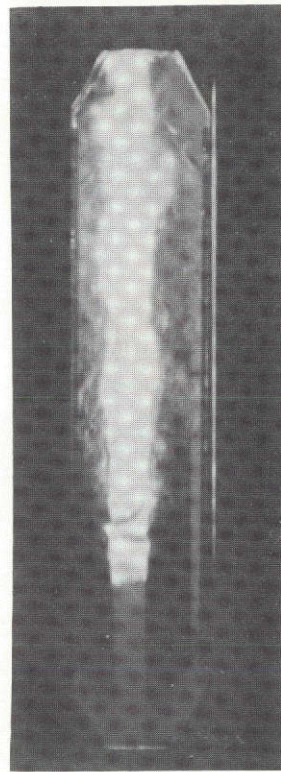
Figure 2. - Flame spreading at low gas velocities.



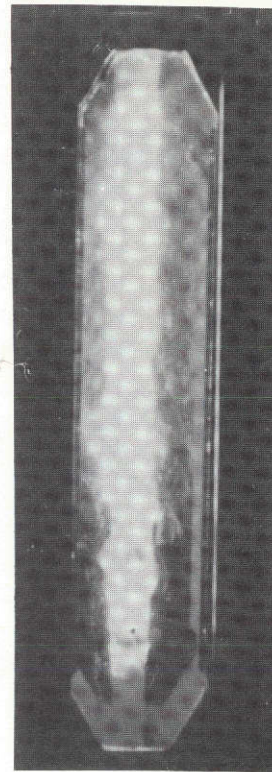
Time, T_1



Time, T_2



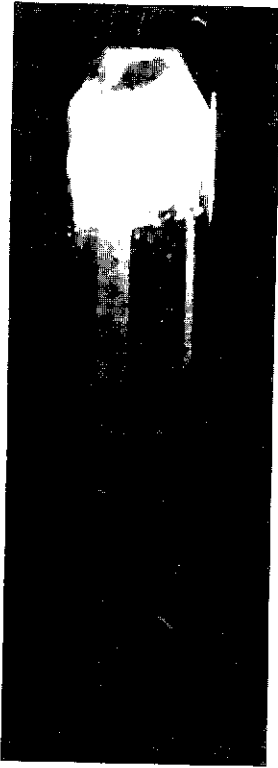
Time, T_3



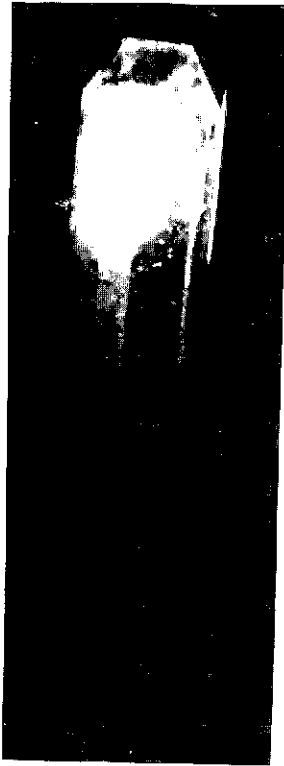
Time, T_4 (where $T_4 > T_3 > T_2 > T_1$)

(b) Nylon; pressure, ~ 75 atmospheres.

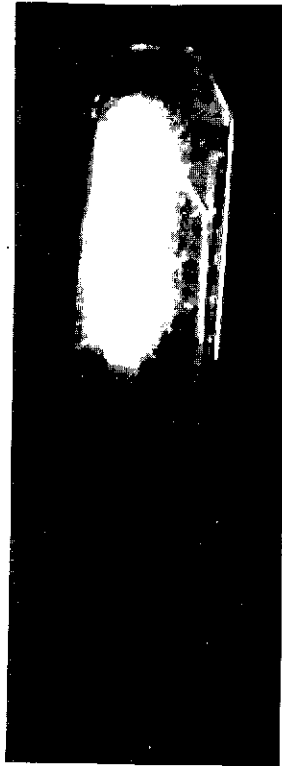
Figure 2. - Continued.



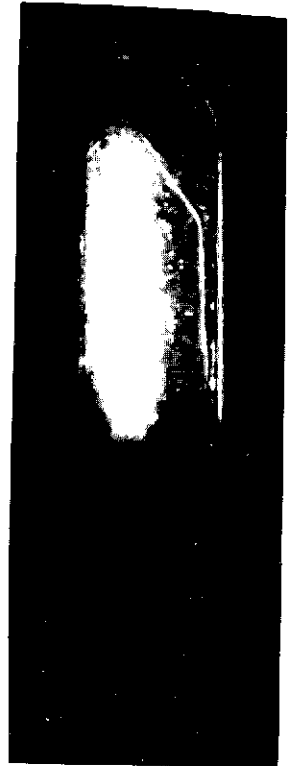
Time, T_1



Time, T_2



Time, T_3



Time, T_4 (where $T_4 > T_3 > T_2 > T_1$)

(c) Teflon; pressure, ~ 75 atmospheres.

Figure 2. - Concluded.

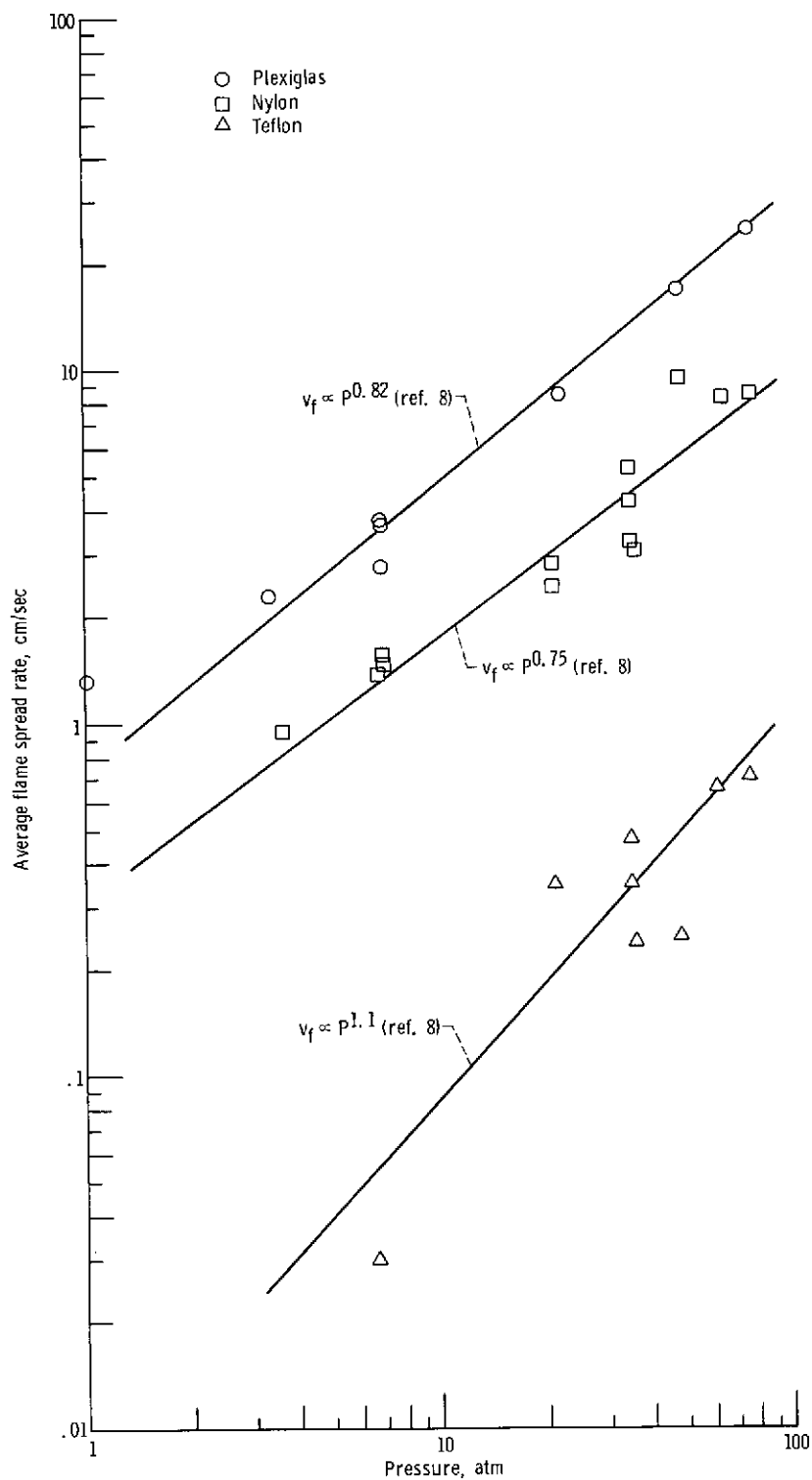
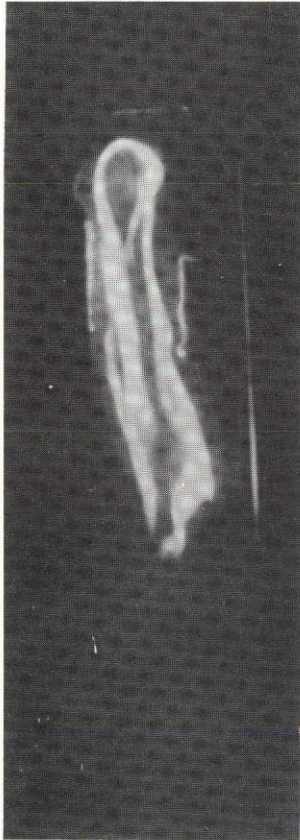
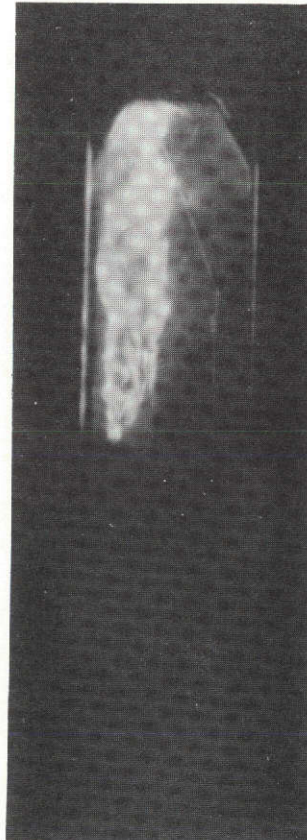


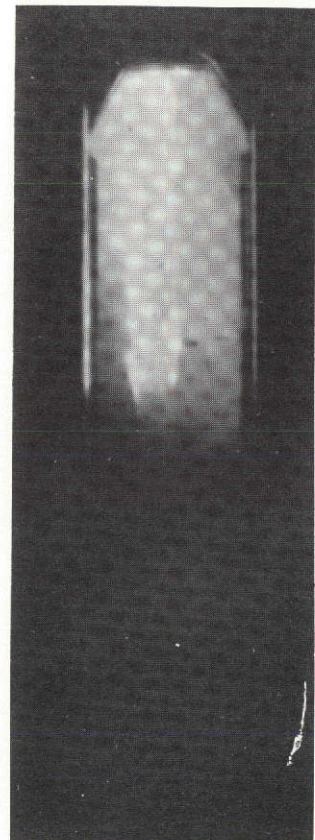
Figure 3. - Effects of pressure on flame spread rate. Average gas velocity, 16 centimeters per second; oxygen concentration, 1.0 mole fraction.



Pressure, 1 atmosphere



Pressure, 20 atmospheres



Pressure, 62 atmospheres

Figure 4. - Effect of pressure on flame geometry for nylon.

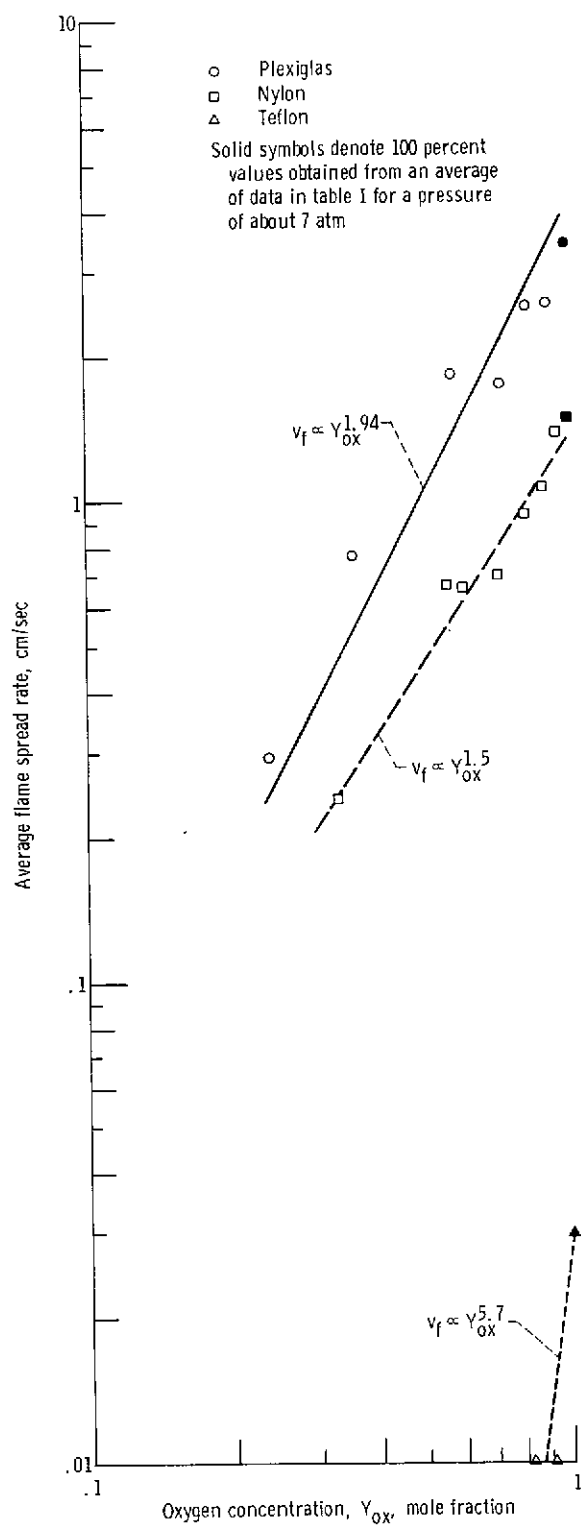
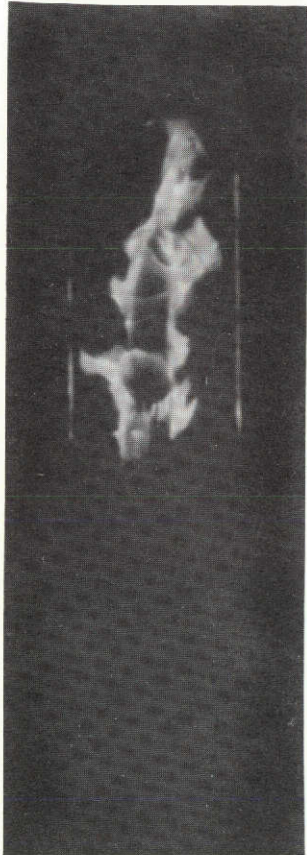
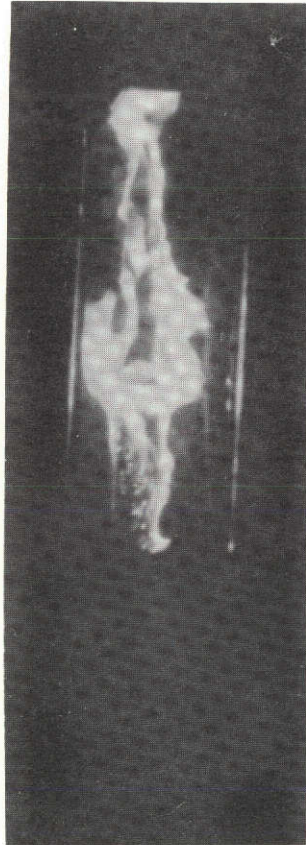


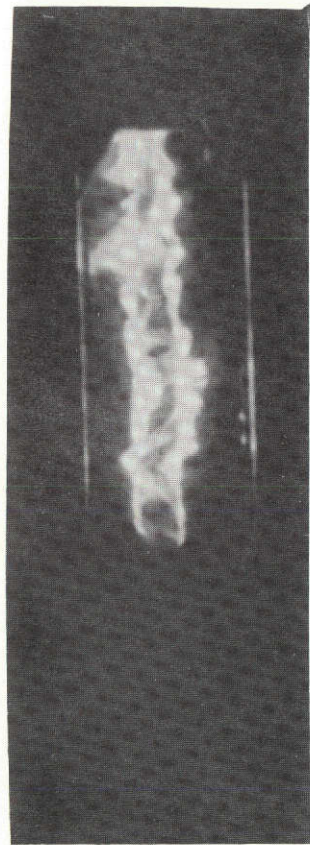
Figure 5. - Effects of oxygen concentration on flame spread rate. Average gas velocity, 15 centimeters per second; pressure, 7 atmospheres.



Mole fraction, 0.20



Mole fraction, 0.72



Mole fraction, 1.0

Figure 6. - Effects of oxygen concentration on flame geometry for nylon.

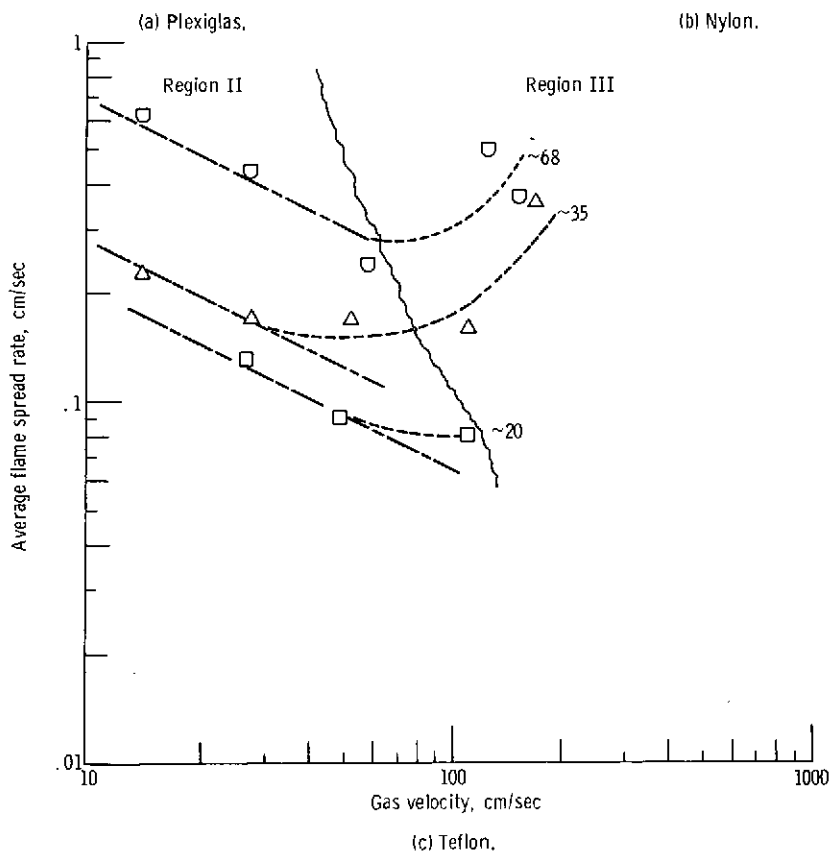
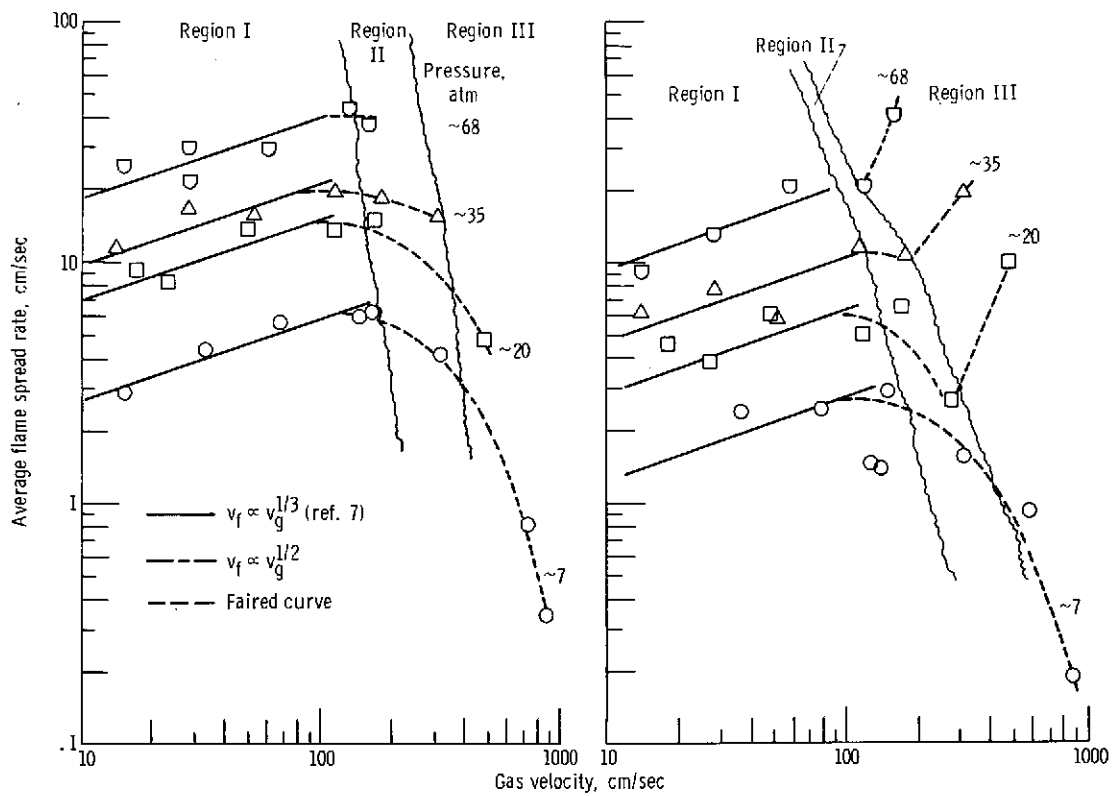
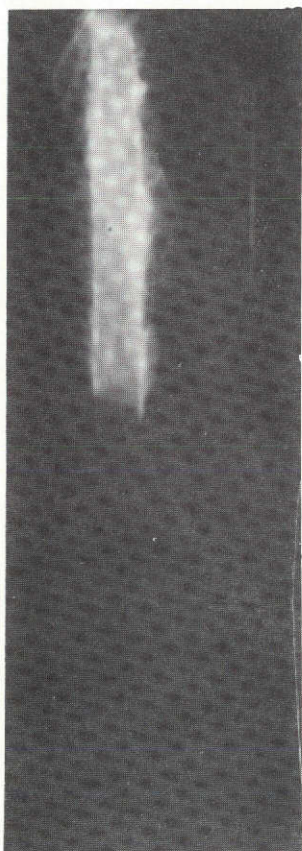
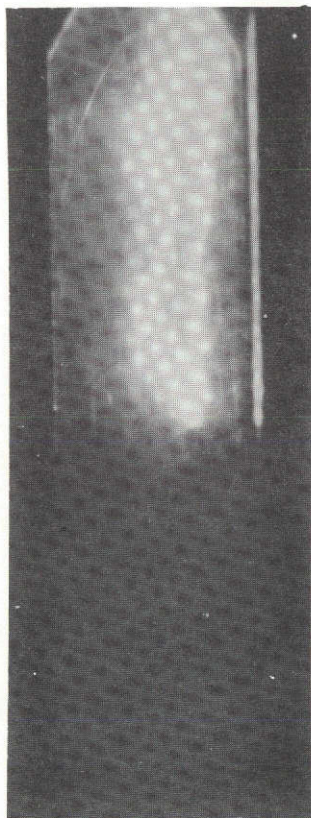


Figure 7. - Effects of gas velocity on flame spread rate. Oxygen concentration, 1.0 mole fraction.



Gas velocity, 17 cm/sec



Gas velocity, 36 cm/sec



Gas velocity, 79 cm/sec

Figure 8. - Effects of gas velocity on flame geometry for nylon.

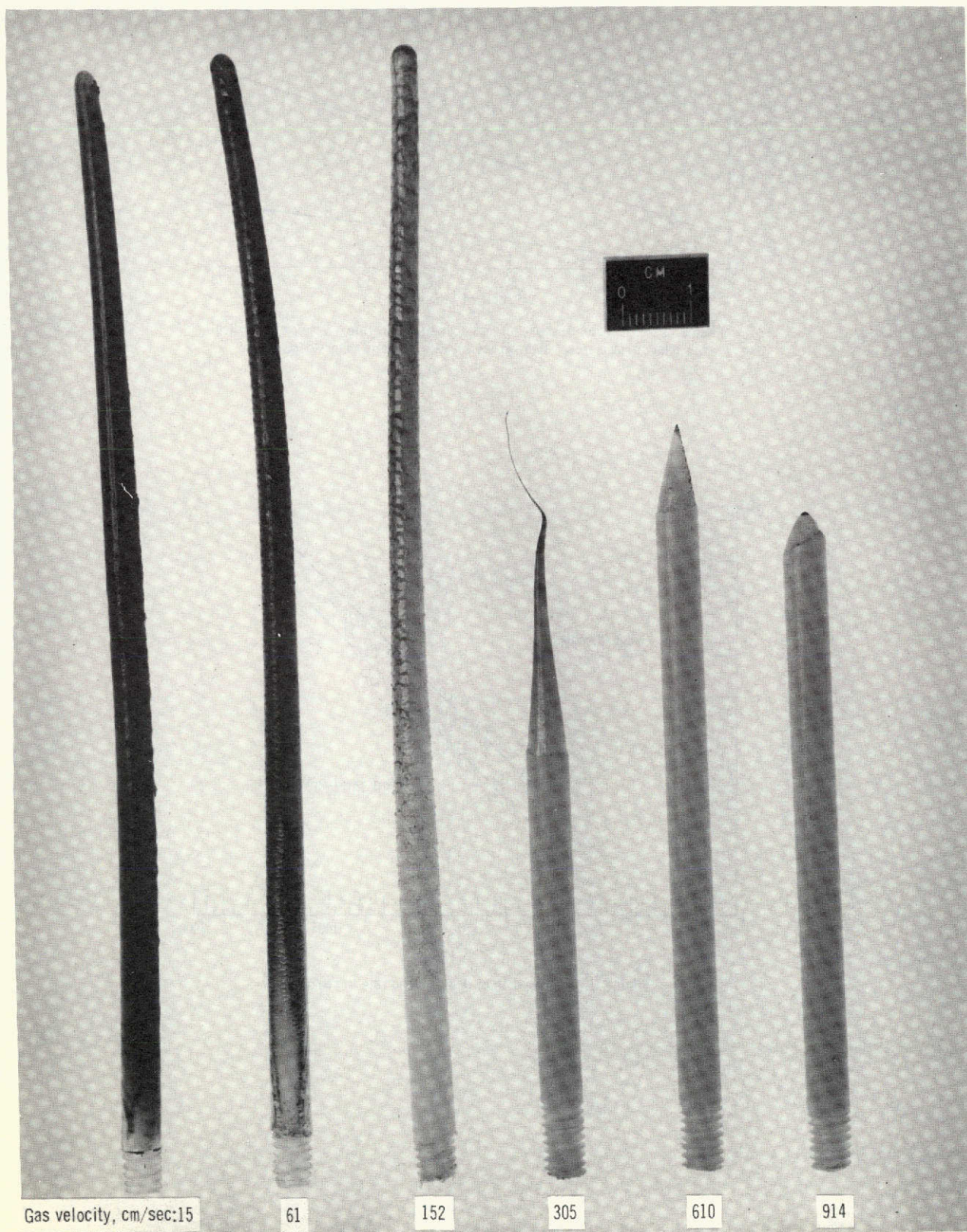


Figure 9. - Effects of gas velocity on char residual for nylon.

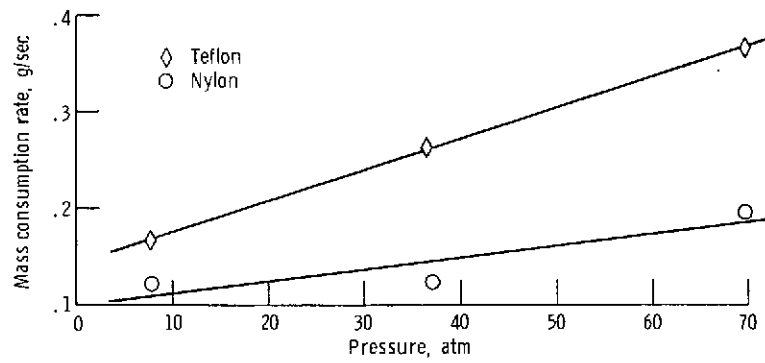


Figure 10. - Effects of pressure on mass consumption rate. Specimens ignited over total surface area. Average gas velocity, 16 centimeters per second.

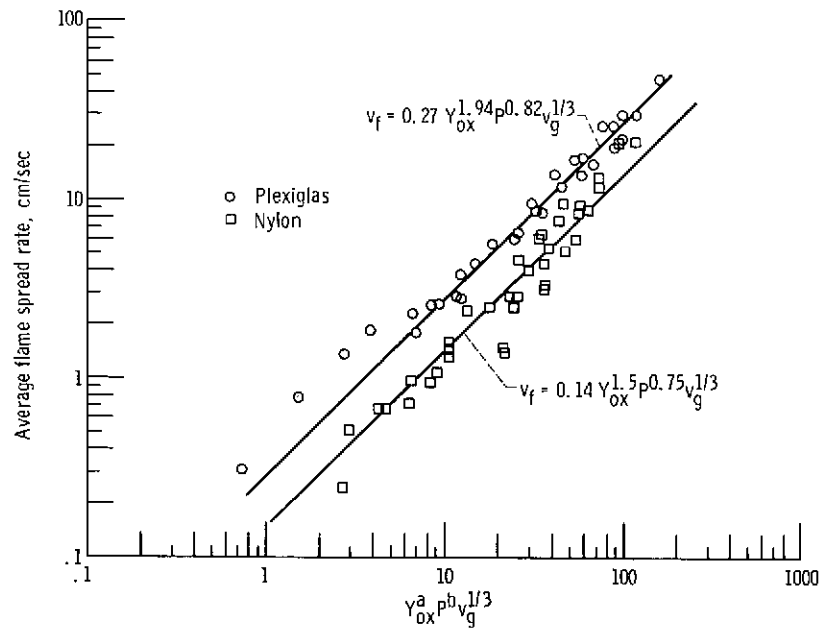


Figure 11. - Correlation of flame spread rate in region I.

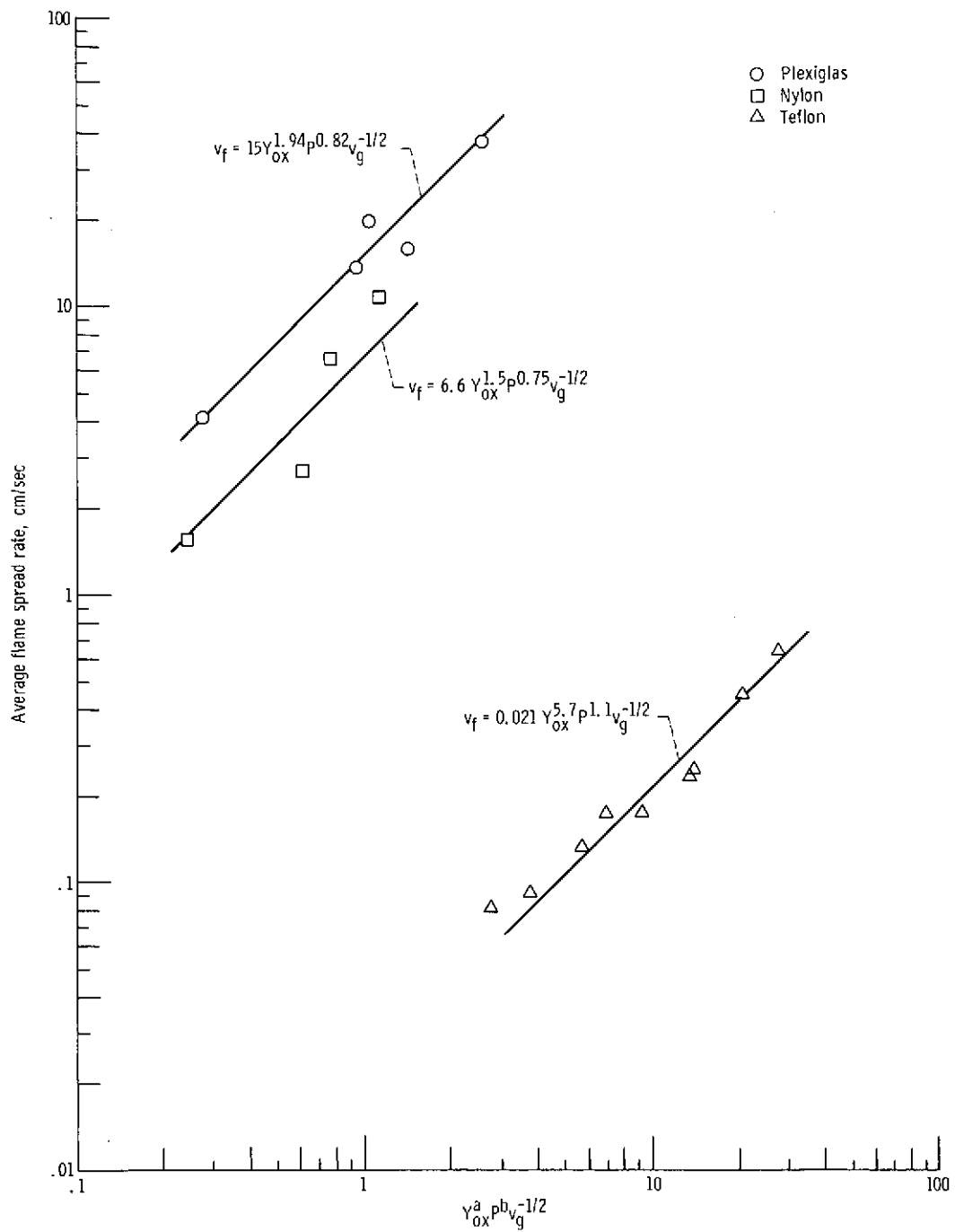


Figure 12. - Correlation of flame spread rate at high gas velocities (region III).